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North-Up, Track-Up, and Camera-Up Navigation of Unmanned Aircraft Systems

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To optimize UAV reconnaissance operations, direction of viewing and direction of travel must be allowed to diverge. Our challenge was to design a control and display strategy to allow the operator to easily look where they're going, go where they're looking, and look and go in different directions. Two methods of control were devised to align traveling forward, viewing forward and commanding forward. The operator can command the UAS to turn to camera or command the camera to point in line with the direction of travel (eyes forward). We have also introduced a new camera-up map orientation. The operator can easily cycle through North-up, track-up, and camera-up to provide the best link between the exo-centric and ego-centric frames of reference. Ego-centric and exo-centric perspectives allow the operator to combine or separate the vehicle's movement and the camera's view to optimize the search task while maintaining situation awareness of flight hazards.

As humans moving through our environment, we have a natural orientation. We move in the direction of our natural stride and our eyes are oriented in that same direction. We can look from side to side and up and down to insure our movement will not be impeded or unsafe but we always retain our visual orientation as the direction of locomotion. When we operate a manned ground or air vehicle, we retain a natural orientation for movement that is aligned with the orientation of our scan. Our orientation for locomotion is naturally ego-centric.

When operating an unmanned aircraft system (UAS) that can move in any direction, there is no natural orientation. In addition, there are no visual cues or kinesthetic cues such as gravity and momentum to provide an orientation. In most situations, the operator must orient to the direction of movement, using a camera orientated in the same direction to prevent collision while navigating to the desired location. However, in some situations it is necessary to orient the camera in other directions, such as during a search and rescue where the camera is scanning a broad area. In these situations it may be necessary to rapidly change the direction of movement to the direction of the camera, for example when detecting a person to be rescued.

This paper describes a methodology of command and control that enables the operator of a UAS to resolve the conflict between the camera orientation and the vehicle's direction of movement. A combination of ego-centric and exo-centric perspectives allows the operator to combine or separate the orientations of the vehicle's movement and the camera's view to optimize the search task while maintaining situation awareness (SA) of the flight hazards.

Review

Orientation is a key cognitive component when navigating through a three dimensional space. Early studies in cockpit displays have established two frames of reference, ego-centric and exo-centric, from which people draw their orientation (Jensen, 1981; Spradlin, 1987). To accurately maintain orientation, the operator must cognitively couple these two reference frames, which traditionally have corresponded with the map (exo-centric) and the forward view of the world (ego-centric; Aretz, 1991). These basic frames of reference have become established as fundamental and spread from manned aviation, to virtual environments, to teleoperation of UASs (Mintz, Trafton, Marsh, & Perzanowski, 2004).

To navigate, an operator must continually associate local situation awareness with global situation awareness to answer the question, Am I where I should be? The ego-centric frame of reference is generally characterized as a bottom-up, user-centric perspective. It primarily supports an inner loop of control of the axes of aircraft rotation (pitch, roll, and yaw) necessary to stabilize the aircraft (Wickens, Liang, Prevett, & Olmos, 1994). An ego-centric frame of reference also supports short-range navigation tasks (limited to line of sight), such as the maintenance of aircraft heading and obstacle avoidance. This supported information is collected, assimilated, and maintained as localized SA. The exo-centric frame of reference is generally characterized as a top-down, world-based perspective. It supports an operator's need for extended spatial location information. The exo-centric frame of reference supports information characterizing the geographical location of the aircraft, and its relationship to landmarks, terrain, other aircraft, weather, and proposed and alternative flight paths. This supported information is collected, assimilated, and maintained as global SA.

Previous research on glass cockpit flight displays has generally focused more on supporting ego-centric and local SA than exo-centric and global SA (Wickens et al., 1994). However, research and design work have led to the inclusion of a "Track-up" orientation in electronic maps (Aretz, 1991). Track-up has taken the utility of a pure exo-centric frame of reference provided by the North-up map orientation and performed the proper rotation of the map to orient those world-based references on the map to an ego-centric based perspective. The inclusion of track-up has aided pilots in bridging the gap between the pure exo-centric (map) view and the pure ego-centric (out-the-windscreen) view. However, UASs remove the pilot from the vehicle and hence remove the information derived from the out-the-windscreen view. In an attempt to replace this necessary view designers are using cameras to provide the ego-centric perspective.

As UAS design has progressed, it has often departed from a traditional aircraft configuration of nose, wings and tail. Nose and tail have disappeared, and cameras are no longer limited to providing a forward view. With the increased flexibility of vehicle and camera movement comes an unintended consequence. The UAS operator has lost a fundamental and innate characteristic of orientation, front and back. The purpose for most UAS flights is to give the operator a view. UASs fly to see, they do not necessarily need to see to fly. This is a major shift in how the control system should be designed. In a user-centered design approach to UAS operator controls stations, Chappell and Dunlap (2006) determined that the operator needs to be able to "fly the camera," to best accomplish their search tasks. To provide this capability, we must first determine how the orientation of the vehicle, the direction of movement, and the direction of the camera interface with the operator's mental model, the navigation displays, and the movement controls.

In the past, the operation of a UAS typically involved two individuals, one to control the vehicle and another to control the camera. The two worked closely together to get the vehicle to the location where the camera could see the area of interest. As vehicles got more automated and the user interfaces made the operation of the vehicle and the camera easier, a single operator was able to control both the vehicle and the camera. When these functions were combined, the necessity to address the difference between the camera orientation and the vehicle's orientation became very important.

Types of Navigation

The UAS operator needs the option of different methods of navigation: a pre-determined flight route, a point-to-point real-time routing, and directional control also called teleoperation. Flight along a pre-planned route allows the operator to investigate terrain and obstacle hazards prior to flight and plan for wind and visibility impacts. Specifying a point-to-point routing in real time is more flexible than following a flight plan and less workload than teleoperation. This method of navigation involves commanding a location and may best be performed by selecting a waypoint on an electronic map. For a discussion of this type of navigation using an interactive point-and-click approach see Chappell, 2007. Teleoperation involves commanding a direction in four dimensions by specifying a continuous speed, heading, and altitude. Teleoperation is most often performed using visual references and requires constant control input for vehicle movement. Neuman and Durlach (2006) have found that a game controller provides better UAS control than a mouse for teleoperation and this type of control has become the recognized standard for modern UASs.

The operator can switch between these three methods of navigation during the flight for optimal effectiveness and efficiency. For example, the routing to and from the area to be surveyed may be pre-planned, a new waypoint may be created to get the UAS near where it is needed based on changes in the situation. During the actual observation of the area or object of interest, the operator may choose to use manual control which provides the most flexibility in vehicle location.

Types of Maps and Tasks

Research has shown that the type of map can influence the performance of different tasks. For example, Aretz (1991) found that a track-up alignment is better for determining which way to turn because it eliminated the need for mental rotation. With a north-up alignment participants recalled the location of landmarks more accurately. Maps can also be either two-dimensional or three-dimensional. Two-dimensional maps provide an accurate representation of distances and therefore are best for navigation using a route plan. Three-dimensional perspective maps more closely align with the image from the video and therefore are best for determining the location of objects in the field of view. The video and the map can be combined on the operator's display. Calhoun, Ruff, Lefebvre, Draper and Ayala (2007) found that a picture-in-picture format where the video was overlaid on a synthetic terrain map reduced the search time for landmarks. Drury, Richer, Rackliffe, and Goodrich (2006) found that search performance was superior with an orthorectified image overlaid on a map. An operator interface that provides all types of maps and methods of combining them with the video is the approach that the authors recommend to provide the best interface for the three methods of navigation and the visual search tasks.

Orientation Conflicts

The biggest challenge for a single operator of both the vehicle and the camera is the combined task of teleoperation and visual search. The operator needs to be able to explore an area, moving around in it, while maintaining awareness of the vehicle's location and clearance from obstacles and restricted airspace. The user interface designer must determine how the orientation of the vehicle, the direction of movement, and the direction of sensing interfaces with the operator's mental model, the navigation displays, and the movement controls. If the camera orientation is moved away from the vehicle direction of movement, there are three options to proceed with manual direction control: 1) automatically converge the direction of movement with the direction of the camera such that commanding a forward motion turns the vehicle to the direction of the camera, 2) keep the direction of movement and the camera direction independent, and 3) cause the convergence of the direction of movement and the camera direction to be based on operator input.

Video games require the operator to control vehicles or personnel locomotion and allow both ego-centric and exo-centric camera views in all directions. Our research on these games revealed two approaches to resolving the differences between camera orientation and vehicle orientation. The most common approach was to permit the person/vehicle to move independently of the camera direction. Some games, however, converged the two orientations such that as the camera was panned, the vehicle would turn to follow; commanding forward motion with the joystick caused the vehicle to move in the direction of the camera.

A UAS in service in combat (Carey, 2007) allows the operator to continue in the direction of movement after panning the camera away from forward; however the first input to the movement control results in a change in direction to that of the camera, at a fixed speed. For example, the operator may be travelling north at ten miles per hour, turn the camera to the west, and any input to the movement joystick results in an immediate turn to the west at a commanded speed of two miles per hour. This vehicle can also be flown by selecting a point within the video field of view and commanding the camera and vehicle to that direction.

These approaches provide an effective but inflexible means of converging the direction of travel with the direction of viewing. If the UAS operator is always going in the direction of the camera the control system design would be straight-forward, however this poses an undesirable and unnecessary restriction on the operation. Not only do UAS operators need to look around as they move in a particular direction, they also need to look in a particular direction while travelling in a different direction. A simple example is a search pattern along a road; the vehicle travels in the direction of the road while the camera is pointed down or to the side.

New Contribution

Our challenge was to provide an interface that preserves both the camera and vehicle orientations with a mechanism to synchronize the two perspectives using the map and the video. We developed a display philosophy that integrated the orientation of both the camera and the direction of travel in the *video* and the *map*. We also developed a control approach to not only integrate the two directions but also permit divergence with ease.

Figure 1. Image from camera video with direction of vehicle track arrow and compass arrow.

Figure 1 shows a typical image displayed to a UAS operator from the camera video. Figure 2 shows the typical map in a track-up orientation as would be found in current UAS displays, as well as in manned aviation glass cockpits. The triangles show the field of view. In addition to this track-up map view, our user interface allows the operator to easily switch to a new map option, a camera-up orientation to align the map with the "out-the-window" view provided by the camera. This new map orientation eliminates the need for the operator to mentally rotate the map to align with the camera view. Figure 3 shows the map in this camera-up orientation. Even in this static representation it is evident that the landmarks in the video field of view (Figure 1) are more easily matched with those on the map, thereby achieving integration between ego-centric and exo-centric perspectives. Note that the video in Figure 1 contains an overlay of the direction of travel (the black arrow in the lower center) and the compass arrow indicating north. The maps contain the arrow for the direction of travel, the triangle for the field of view of the camera, and the north arrow. These cues further help to integrate the two perspectives within the framework of each individual perspective.

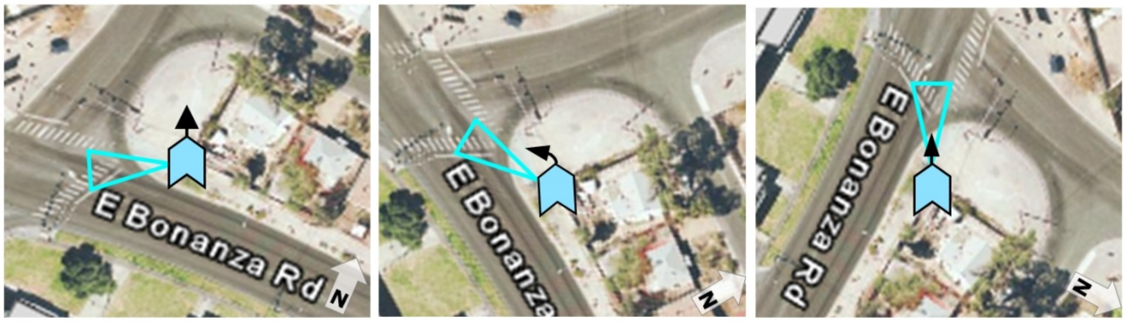

Figure 2. Track-up map display as the operator turns to fly in the direction of the sensor (teal triangle).

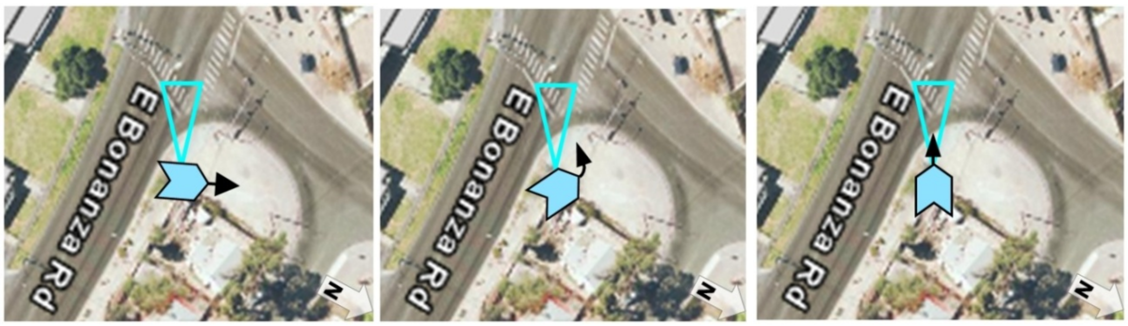

Figure 3. Camera-up map display as the operator turns to fly in the direction of the sensor (teal triangle).

During teleoperation while performing a visual search, the operator is actively diverging the direction of travel and the camera view. The camera now provides the synthetic ego-centric perspective which is not necessarily forward along the direction of travel. This capability poses a significant potential for disorientation. The expectation is that commanding a forward direction on the control matches travel in the direction of the camera view. When the results of the command inputs do not meet the operator's expectations, a quick way to synchronize the two is required. To accomplish this, we have created a control which we labeled "turn to camera." When the operator selects this option, the direction of travel aligns with the camera's aim point. See Figure 2 for the sequence as the track-up map turns with the vehicle. See Figure 3 for the sequence as the camera-up map symbology turns with the vehicle. The controls align with the new direction of travel. Viewing forward, travelling forward, and commanding forward are all aligned.

This control feature gives the operator a method to command the UAS to "go where I'm looking." It is also important to command the camera to "look where I'm going" but then to quickly return to the previous aim point, "look back." The interface we have designed has an eyes-forward function with a complementary command to return to the previous view.

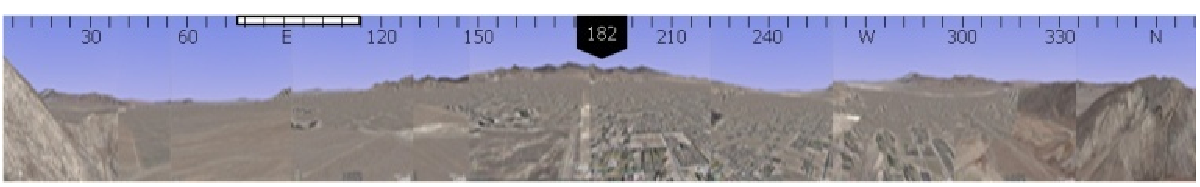

Figure 4. Panorama display. Compass tape is centered on vehicle direction of travel. White band represents camera field of view.

In addition to the camera's field of view for searching, we have designed a panorama display (Figure 4) that is centered on the direction of travel. (See Chappell, 2007 for further description.) The compass overlay also depicts the field of view and direction of the camera (white band). The panorama is accomplished by periodically taking a 360 degree sweep at a horizontal angle. The image is split such that the direction of travel is in the center and the opposite direction is shown at the right and left edges. The panorama image not only provides orientation, but is important for collision avoidance, especially in environments such as urban canyons.

Discussion

Research has shown that the task dictates the best map orientation: North-up, track-up, two-dimensional, and three-dimensional. Our design allows an easy transition between these map types to optimize the operator's task performance.

Our review of the research on vehicle control and orientation combined with our investigation of the current UAS interfaces has illuminated the flaw in the integration between map and video views. This is especially acute when the operator is actively commanding the vehicle movement and camera aimpoint. Our goal was to give the operator maximum flexibility in the vehicle's movement and the view the camera provides and a method to link the situation awareness that the operator derives from both views into one comprehensive mental model. To provide this capability we have a new map orientation labeled camera-up and have included directional cues in the map and video to link the two. We also recognized the need for new controls such as "turn to camera" which realign the vehicle directional controls with the camera aimpoint. Initial simulation trials have shown that the addition of a camera-up map orientation and the ability to take a positive action to realign the manual controls with the direction of the camera constitute a significant contribution to the control of UASs. This combination of ego-centric and exo-centric perspectives allows the operator to combine or separate the orientations of the vehicle's movement and the camera's view to optimize the search task while maintaining situation awareness of the flight hazards.

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